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Glacial Diversion of Drainage

(With especial reference to the phenomenon of the "Lost Gorge")

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ABSTRACT

Glacial diversion of drainage has been a factor of first importance in determining the existing pattern of stream courses in regions occupied by Pleistocene continental glaciers. Aside from the well-known, large scale changes resulting from deposit of drift, transection of minor and major water partings by overflows from glacier-ponded waters was an important item in the reordering of stream courses. The efficacy of this type of erosion does not seem to have been fully appreciated. Deep gorges were evidently eroded with great rapidity by such overflow streams. In some places the cuts thus made served of themselves to confirm postglacial drainage in new channels. Elsewhere glacial erosion modified and commonly greatly enlarged the water-cut overflow channels. There is a marked tendency to compel the glacially reconstructed drainage to arcuate courses which reflect the outline of the normal lobate margins of the ice front.

INTRODUCTION

The purpose of this paper is to call attention to the important role that diversion of drainage, brought about by the positions of the margins of the Pleistocene continental glaciers, has had in fixing the pattern of existing stream systems.

The reference, here, is not to the extremely numerous, and commonly far-reaching, diversions resulting from the deposit of glacial debris during the

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period of the last deglacierization. Although the effect of shifts from glacial deposits cannot always be fully discerned, the cause and the manner of their application are obvious.

The phenomenon of drainage diversion forced by glacier margins is also well known, is frequently referred to, and examples are often cited. It does not, however, seem to have been analytically and systematically treated. Moreover, the circumstances of its initiation and application are apparently not always clearly appreciated.

The prompting to undertake the following exposition derives from field acquaintance for a number of years past with a rather extraordinary example of such diversion. This instance is the development of the Cayuta[1] Lake outlet drainage. In it evidence was preserved of episodes which, as interpreted, afford clues that permit a degree of understanding of other occurrences not otherwise possible.

ACKNOWLEDGMENTS

In part what is set down here in regard to the Cayuta Lake outlet drainage depends on the observations of two former graduate students in Cornell University, Miss Lois Sweet, and Mr. Frank L. Le Roy. Their master's theses, entitled respectively "Rock Gorges Associated with the Outlet of Cayuta Lake," and "Outlet History of Peri-Glacial Cayuta Lake," are deposited in the Cornell University Library. It should be said, further, in their behalf, that they did not have available to them the vertical stereo-pair photographs of the area used in making this study. Since much of the country is wooded, topographic details, practically undiscoverable on the ground, are revealed by the overhead stereoscopic views. In what follows credit for their specific contributions is given by the notation in parentheses (Sweet), (Le Roy) as the case may be.

It is also a pleasure to acknowledge a grant in aid to provide for illustrations of this study made to the author by the Trustee-Faculty Committee on Research of Cornell University.

PONDING AND OVERFLOW

The "Lost Gorge"

Discovery. The author's attention was arrested, in about 1916, by the anomalous form of the channel of a small stream draining from a gorge in

[1] Caution: Do not confuse Cayuta Lake with Cayuga Lake. This discussion centers about Cayuta Lake. The larger, better known, Cayuga Lake is situated 12 miles to the northeast of Cayuta Lake and is referred to only to establish locations and relationships.

the hills about two miles southeast of the village of Alpine, N. Y., and mapped on the Ithaca, N. Y., topographic sheet. This minor drainage was tributary to a larger stream, Cayuta Creek, flowing over the mile-wide, level floor of the Pony Hollow valley (Fig. 1). The channel of the small stream

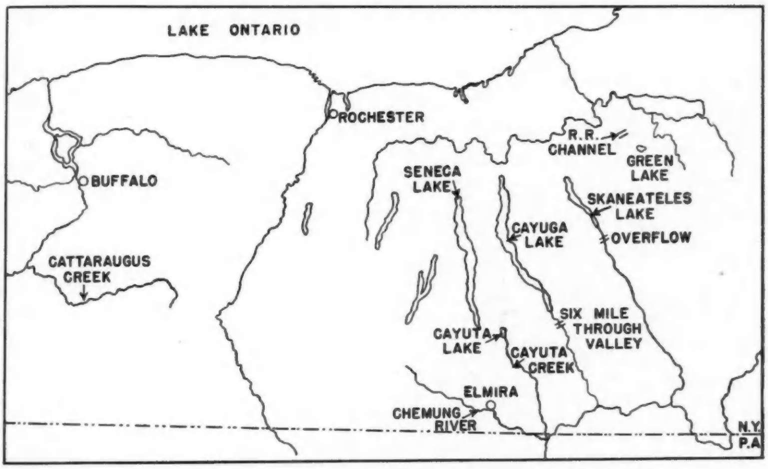

FIG. 1.—Map of Central New York to show localities referred to in the paper.

had a nearly flat floor (Fig. 2) about 400 feet wide where it is crossed by the automobile road from which the picture was made, narrowing to about 100 feet at the outlet of the gorge, that is, in a distance of approximately 750 feet (Le Roy). The sides of the channel, composed of gravel, are steep, and range from 10 to 15 feet in height.

These topographic elements are entirely incongruous with the type and volume of the drainage that could be presumed to be available at such a site. The greatest conceivable amount of water that could be furnished in flood stages would not require a channel of such dimensions. Furthermore, a flood-flow, descending steeply from the hills, could be expected to build up an alluvial fan of coarse debris at the outlet to the gorge, instead of sluicing out the wide, flat-bottomed channel which here exists. Indeed, alluvial fans are actually the normal occurrences at similar emergences in the locality. By contrast, this channed-bottom is grass-covered, is used as a meadow, and does not appear to have been affected for decades by anything more than a perennial trickle of drainage along its axis, with perhaps a thin sheetflow of water over its floor in periods of heavy precipitation or active snow-melting.

The gravels through which the channel is cut are those of the glacial outwash plain that constitutes the westerly-inclined, flat floor of the Pony Hollow valley (Fig. 3). It is clear that after the ice melted off, and continuing for a period after deposition of the outwash had ceased, this site was the scene of a drainage episode now inoperative and apparently long since terminated.

FIG. 2.—Flat-bottomed channel at the outlet of the "Lost Gorge."

Overflow channels. By analogy with other channels of similar form and of known origin, this type of channel is definitely indicated to be the product of the sweep flow of a large volume of sediment-free water, specifically the overflow of a large or well-fed lake. They are "abandoned stream channels with their peculiar conformation and unmistakable characters" (Fairchild, 1895, p. 355). Such channels in the drift are commonly recurring items in the Finger Lakes region of Central New York. Another example near the Cayuta area is illustrated by Figure 4. This channel carried the overflow from a small lake, ponded behind a moraine, about 4 miles southwest of Newfield, N. Y. It probably functioned only for a relatively short period, and perhaps it was supplied with some sediment from the moraine deposits, that is, sweep erosion was supplemented by scour erosion,

hence it does not have the abrupt banks characteristic of the typical outlet channels.

Similar channels occur at the overflow sites of the ice-dammed, proglacial Finger Lakes. A representative example is illustrated by Plates 13 and 19 in a paper by the author (von Engeln, 1919). These show the overflow channel of a lake which occupied the Onondaga Valley, north of Tully, N. Y. In one view the channel is eroded in moraine and is now all dry; in the other it is incised below the level surface of an outwash plain and is oc-

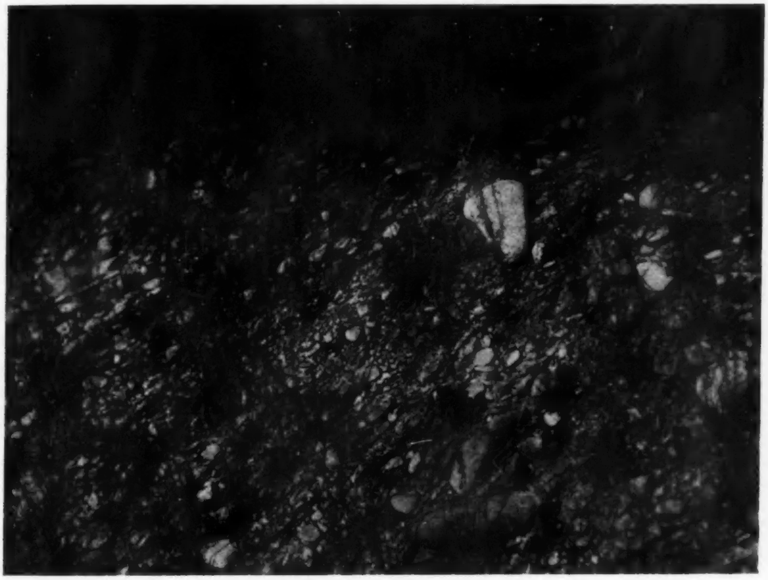

FIG. 3.—Section to show the composition of the outwash gravel (valley train) forming the flat floor of Pony Hollow valley.

cupied by an underfit stream. The point to be emphasized is that lake overflows of low gradient regularly sluice out channels of this canal-like cross-section form (with steep sides, and flat bottoms; conspicuously wide in comparison to their depth) when cut into unconsolidated materials. The great width results, perhaps, from the wide spread of the outflow waters in a thin sheet when they first enter upon a low-gradient area composed of unconsolidated materials. As sweep erosion makes itself effective an increasing depth of current is concentrated in a definite channel, which, however, retains the characteristic of notable width of bottom, with the result that the final

channel is incised at this width. The Detroit River, and the Niagara River above the falls, are instances of such channels still occupied. As in the case of the Niagara River the channel is probably brimful while it is functioning, because the efficacy of the sweep erosion on a low-gradient surface is chiefly dependent on the hydraulic head. Consequently the channel is brought to "grade," that is, it attains its maximal permanent depth, when the full volume of the sediment-free overflow is accommodated at a current rate which just

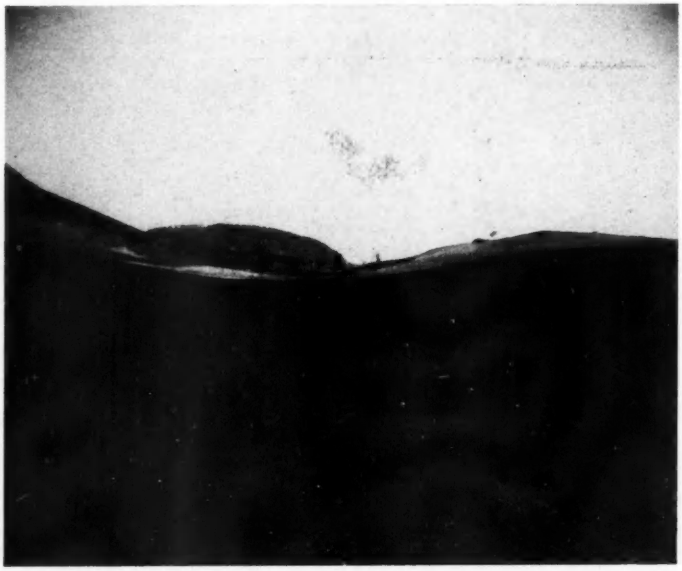

FIG. 4.—Overflow channel southwest of Newfield, N. Y. The banks are not so steep as those of more representative developments.

fails of achieving further sweep erosion of the floor. This channel form is rather convincingly demonstrated by the remmants of the channel of the Niagara River preserved above the level of the gorge walls on both sides of the stream, and is especially conspicuous in the section between Lewiston and the Whirlpool (Fig. 5).

The Lost Gorge. If, in view of its characteristics, the abandoned channel near Alpine is inferred to be the relic of a lake overflow the next questions are: What lake? and: What is the nature of the gorge from which the waters emerged? On the Ithaca, N. Y., quadrangle topographic sheet, the gorge valley is represented as that of a ¾-mile long stream descending 260 feet to the Pony Hollow valley floor from a col in the hills at an elevation of 1400

feet, and matched by a one mile long stream descending about 200 feet in the opposite direction (Fig. 6, a and b). Traverse of the gorge proved that this representation was completely erroneous. Instead of ascending to a col, the gorge was found to have a nearly flat floor (Fig. 7), and to lie transverse of the full width of the secondary divide shown on the map. This finding may be regarded as the scientific discovery of the gorge and earned it the soubriquet, "Lost Gorge." It will hereinafter be referred to as the Lower Gorge.

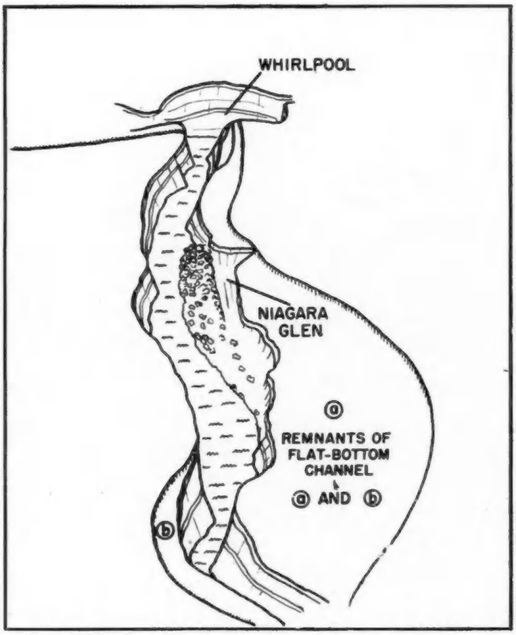

FIG. 5.—Remnants of the flat bottom, steep bank, Niagara River overflow channel in the lower section of the gorge. Drawn from the photograph of a relief model.

Evidently the U.S.G.S. topographers were naively unaware of the geomorphic implications of the flat-floored channel across the outwash and assumed the upstream topography (the area is forest-covered) to match that of similar streams in the neighborhood, which do conform to the representation made on the map. Without traversing its course they contoured this section of the country (by approach only from the two ends of the Lower Gorge) in the ordinary pattern. There is drainage in opposite directions from within the gorge, but this originates in a valley-floor divide on alluvial deposits that

have accumulated post-glacially by weathering and wash of the sides of the gorge.

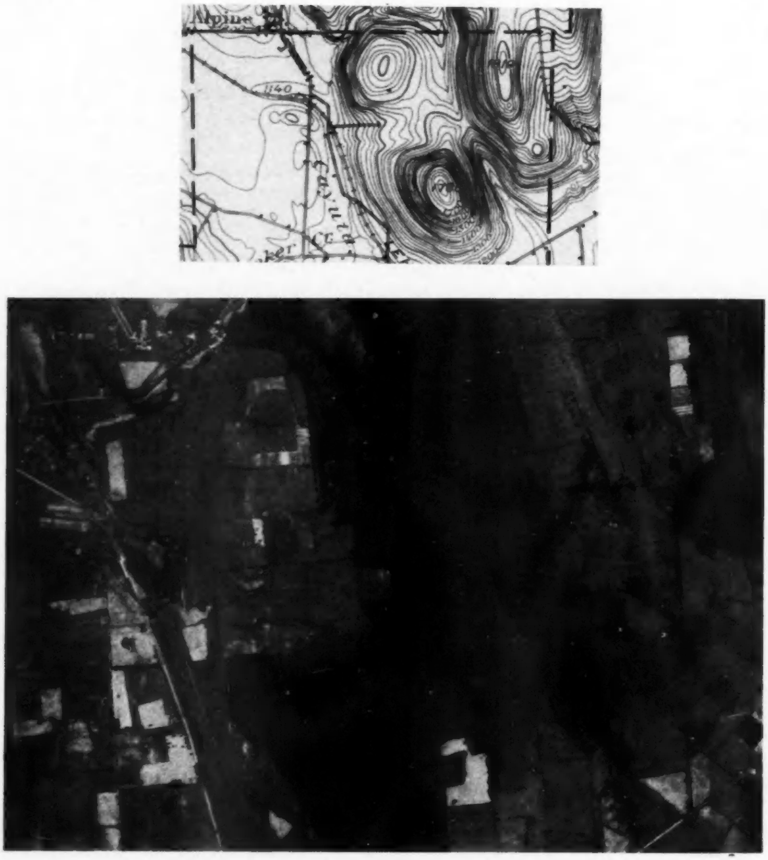

FIG. 6a and 6b. Part of the Ithaca, N. Y., topographic sheet as mapped in 1893, and an aerial photograph of the same area to show the "Lost Gorge" (Lower Gorge) topography in actuality.

Cayuta Lake Drainage History

Ponding of the Cayuta Lake basin. Once the transverse nature of the Lower Gorge was established its origin was rather surely linked with that of two other gorges of similar characteristics previously known and correctly represented on the topographic map. These other two gorges will be

referred to as the Middle Gorge and the Upper Gorge. The three gorges have served to outlet the overflow waters of the Cayuta Lake basin on the north; the Middle and Lower ones only in immediately post-glacial times; the Upper one, locally known as "The Gulf," is still functioning in that capacity.

Cayuta Lake, unlike the chief lakes of the Finger Lakes region (which are glacially eroded rock basins), owes its present existence to a morainic

FIG. 7.—Swampy, impeded drainage of the flat floor of the "Lost Gorge" (Lower Gorge) near its middle section.

dam. The lake is about two miles long and a half mile wide and is situated south of the high point in the floor of a north-south trough that extends past the village of Smith Valley to Mecklenburg. This trough is a through valley fashioned by glacial-water and glacial-erosion modifications of the preglacial stream valley system of those parts. The preglacial divide was near the present site of Smith Valley, from which point a stream then flowed southward to the Cayuta Lake area, the duplicate of small streams that still

exist, tributary to the same drainage, shown on the Ithaca, N. Y., topographic sheet northwest of Cayutaville, N. Y.

During the retreat of the front of the last advance of the Pleistocene glaciers, a massive moraine, easily 300 feet thick, a mile long and a half mile wide, was built across the Cayuta Lake valley immediately southwest of the present lower end of the lake. This morainic barrier diverts the outflow waters of the present lake into the Upper Gorge of the three aligned gorges. The low point in the morainic barrier is 1280 feet (along the course of Catlin Mill Creek), the altitude of the lake surface 1272 feet, and that of the head of the Upper Gorge floor at the outlet only a foot or so lower. In other words, an excavation of slight depth, approximately one fourth mile long, in drift, would serve to return the drainage of the Cayuta Lake area to its preglacial course. Accordingly, if the floor of the Upper Gorge had had a high point as little as ten feet above its actual level, the ponded waters would have followed the preglacial drainage course when the present Cayuta Lake was established. Moreover, the flow of the outlet stream at its upper end is extremely sluggish, a circumstance that warrants the inference that the altitude and low gradient of the floor of the gorge were established either before, or coincidentally with, the fixing of the present level of the lake surface. The outlet waters merely follow a course that was available to them, completely excavated, when the present lake came into existence.

Nature of the gorges. The present author, Sweet (1934), and Le Roy (1938) all are in agreement that the rock floor of the gorge is now veneered with alluvial and weathering wastes. Rich (1908, p. 535) and Tarr (Williams, Tarr, and Kindle, 1909, pp. 164, 221, 225) held that the fill is glacial drift, hence that the gorge antedates the last ice advance. In support of this conclusion they stress the existence of drift-filled gorges tributary to the Upper Gorge near its downstream end. Both Rich and Tarr were preoccupied with a search for evidence of more than one ice advance across the region. It escaped them that these tributary valleys are really hanging valleys in relation to the Upper Gorge. Streams in them are on rock (Fig. 8) and have not yet been brought to accordant junctions with the gradient of the Upper Gorge. Further, although the slopes above these tributary gorges are mantled with glacial debris (they were lines of preglacial drainage courses) the walls of the overflow gorges are thinly surfaced with local weathering waste, as Figure 9, taken in the Lower Gorge, clearly demonstrates. This condition is quite incompatible with the concept of a morainic fill on the gorge floor.

It is clear that the drainage which cut the gorge came from and beyond (N., E., and W. of) the area of the present Cayuta Lake basin. It also follows that, downstream, the wide Cayuta valley was blocked by a barrier

far superior in height to that of the present moraine, because a rock barrier that rises 200 feet above the level of the crest of the moraine is breached by the gorge. To permit the erosion of the Upper Gorge a lake of sufficiently high level to overflow the lowest col in the rock mass to the east had to be created.

FIG. 8.—Hanging valley tributary to the Upper Gorge, Cayuta Lake overflow.

Ice lobes of the Seneca and Cayuga Lake valleys. A barrier high enough to give rise to such a high-level lake could only be provided by glacial ice. About five miles to the west of the Cayuta Lake basin the deep, straight, large, north-south extending Seneca Lake valley afforded a route for a powerful, active current of the Pleistocene ice during the closing phases of its last advance. The ice front had melted back 80 miles from its farthest south stand on this meridian (at Williamsport, Pennsylvania) to the approximate position of the "Valley Heads" moraines across New York State.

The Seneca Lake development of these moraines is at Pine Valley, N. Y., approximately 10 miles south of the Cayuta Lake site. During this stand the ice tongue in the Seneca Lake valley was sufficiently high, massive, and active to send a lobe eastward up the wide valley that was the preglacial lower course of the Cayuta Lake and Pony Hollow drainage. This lobe projected past Odessa, N. Y., and was banked up against the rock hills of the eastern side of the Cayuta valley south of Cayuta Lake. It had one

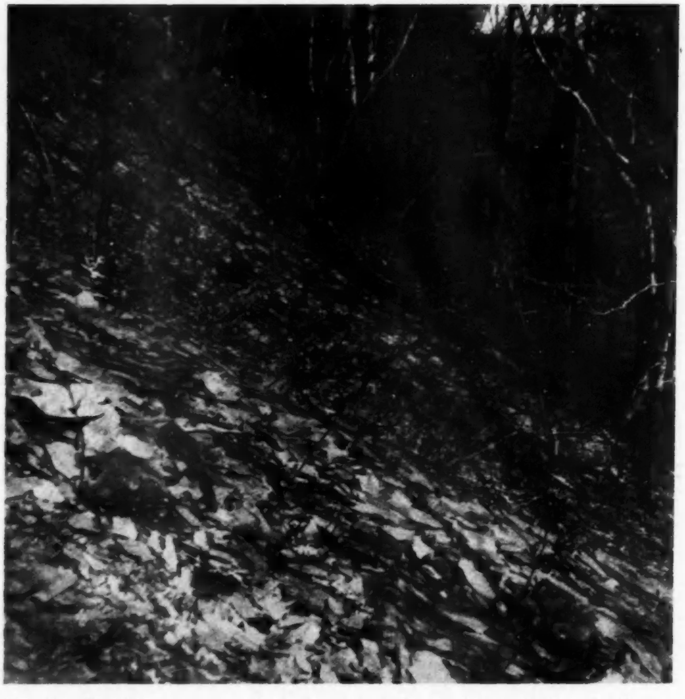

FIG. 9.—Weathering waste of local rock on the walls of the Lower Gorge. No trace of glacial derbris.

termination at the site of the moraine south of Cayuta Lake, and another where the Cayuta valley is joined by the Pony Hollow valley near Alpine, N. Y. There is evidence of considerable morainic deposit at the south-easterly, Alpine terminus, but such accumulations were largely buried by outwash gravels derived from a lobe of ice that projected from the Cayuga Lake valley ice tongue into the Newfield and Pony Hollow valleys, as an almost exact counterpart of the Odessa-Cayuta Lake-Alpine lobe from the

Seneca Lake valley. Around Odessa these gravels were veneered at a later stage by lake clay deposits.

However, since the Cayuga Lake valley ice-tongue was feebler and more remote than that of the Seneca Lake valley tongue which supplied the Odessa-Cayuta Lake-Alpine lobe, and since the line of the general ice front at the time of the deposit of the Valley Heads moraine was farther and farther north toward the east, melt waters, from the Cayuga lobe, draining westward in the Newfield-Pony Hollow valley, had ceased to flow at a time when the lobe from the Seneca Lake valley was still in active existence in the Odessa-Alpine area. In other words, the Cayuga Lake valley lobe had by then so far shrunk that all its melt water and deposits were being contributed to the Cayuga Lake valley drainage.

The outwash gravel from the Cayuga Lake lobe constitutes the level floor of the Pony Hollow valley at the outlet of the Lower Gorge. Its surface is practically unmodified by postglacial erosion except where it was cut by the Lower Gorge drainage as this emerged from the valley in rock. This bisection of the outwash is conclusive evidence that the Seneca Lake valley lobe functioned to divert drainage from the Cayuta Lake basin through the three aligned rock gorges after deposition of the outwash from the Cayuga lobe had ceased, and that the erosion and utilization of these gorges was the *final* episode in the glacial history of the area. An interesting side light on this inference is the discovery (Sheldon, 1915) of mastodon remains in the Pony Hollow glacial deposits. These great mammals were evidently occupant of the region before drainage through the Lower Gorge ceased.

Erosion of the gorges. The existence of the ice barrier (as described above) ponded waters from a much wider area than that of the present Cayuta Lake basin. An extensive region to the north, between the Seneca Lake valley and the Cayuga Lake valley, now drained by Taghanic Creek and the streams outflowing from Texas Hollow, was evidently free of ice while the Odessa-Cayuta Lake-Alpine ice lobe persisted. As the ice of the main glacier prevented escape of water from this area to the west, north, or east it was, perforce, ponded to the level of the lowest overflow southward. The Taghanic drainage connects directly with the Cayuta Lake basin over a valley-floor divide hardly more than 30 feet above the level of the lake, and there are marginal channels (Williams, Tarr, Kindle, 1909, p. 158) cutting across the nose of the hill between Texas Hollow and outleting into the Cayuta Lake valley at 1480 feet approximately. Normal precipitation, together with melt waters from the glacier margins ringing all around this relatively wide area, unquestionably provided a huge volume of water for overflow of the expanded lake (Fig. 10). Tarr (Williams, Tarr, and

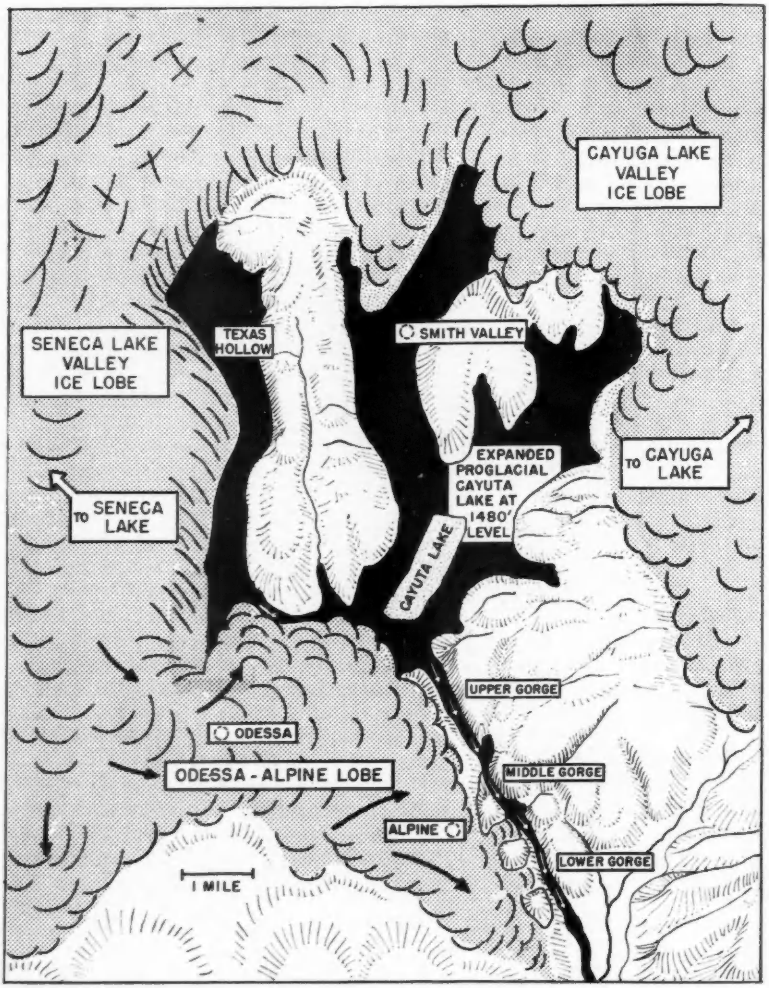

FIG. 10.—Map of the expanded Cayuta Lake and the ice barrier at the 1480-foot level.

Kindle, 1909) maps a hanging delta, with its upper level at approximately 1400–1500 feet altitude, at the lower end of the Texas Hollow channels, and Le Roy (1938) interprets a deposit at Smith Valley (Fig. 11) in the

Taghanic Creek drainage, at about the same altitude, also to be a hanging delta. These deltas mark near maximal, if not maximal, levels of the ponded Cayuta Lake basin drainage.

The first overflow in the Upper Gorge section was, however, at a higher level, 1680 feet, through a channel (Fig. 12) that does not seem

FIG. 11.—Hanging delta deposit at Smith Valley, N. Y. Noted by Le Roy.

to have been noted previously. This stage is shown by the photograph (Fig. 13) of the relief model. At this stage the sites of the Upper and Middle Gorges were buried under the margin of the ice lobe. The highest overflow has the characteristic canal-like cross section, flat bottom, steep sides of such channels cut on a low gradient in unconsolidated deposits. It was short, and was apparently utilized only for a limited period. In the model it is represented as terminated by a waterfall. Actually this descent was more in nature of a rapids than a waterfall. A parallel instance occurs in the high-level overflow southward of Skaneateles Lake. There,

Fig. 12.—Highest overflow channel from the expanded Cayuta Lake, at 1680 feet, as it appeared in 1944. Water flowed from right to left.

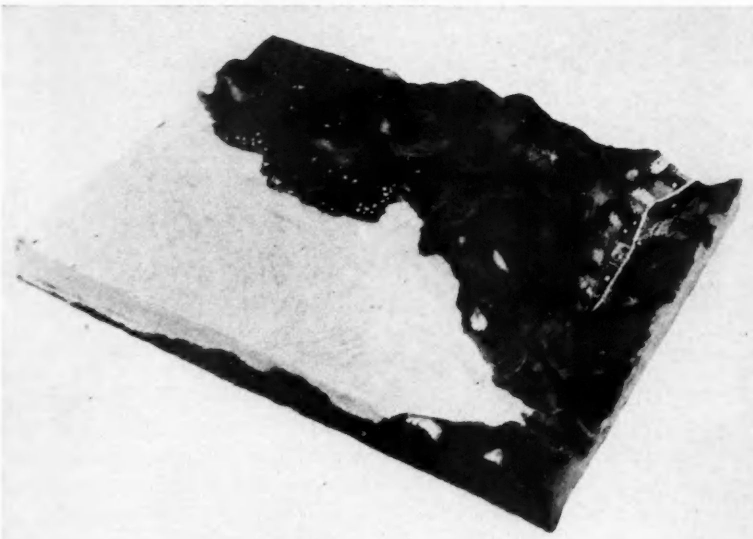

Fig. 13.—Photograph of a naturalistic relief model of the overflow from the expanded Cayuta Lake at its highest level, 1680 feet. The model is contructed to convey the idea of the transition of the area, in time, in three zones, from the glacial occupation in the west, to a barren morainic belt, and to its present aspect, with forest and farm, in the east.

too, (Fig. 14) the overflow waters poured down a steep slope to join the Tioughniogo River drainage.

It will be noted that a secondary lake was, at this initial stage of the Cayuta drainage, ponded on the north side of the col that was the divide between the headwaters of the opposed, short streams that preglacially occupied the line of the Lower Gorge. The topographers who missed this Lower Gorge fixed the divide, by inference, at the elevation of 1400 feet.

FIG. 14.—Part of the high level overflow channel of the ice-dammed Skaneateles Lake, N. Y. There were probably rapids over this steep descent. A small, underfit stream, local drainage, now flows along the far side of the flat-bottom channel.

Sweet (1934) does not venture to state a definite figure for the altitude of the col but thinks it was originally the highest of the three cols in the line of the gorges; Le Roy (1938) fixes it at 1425 feet. Even if the initial overflow in the line of the Upper Gorge was lower than the 1680 feet, postulated above, it still remains that, by any estimate, the col of the Lower Gorge course was so much lower than that in the line of the Upper Gorge as to insure that the Lower Gorge functioned concurrently and independently as an overflow course while the Upper Gorge barriers were being lowered.

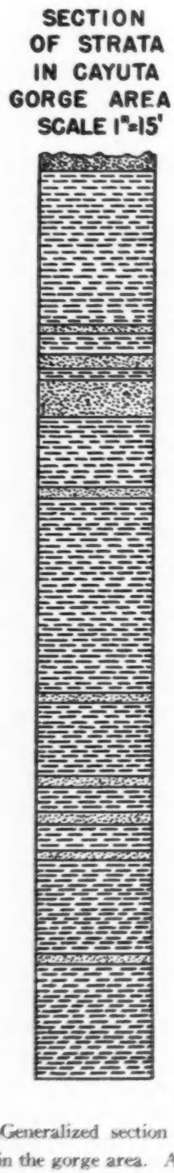

FIG.—Generalized section of the Cayuta beds in the gorge area. After Sweet.

Over this col the large volume of the outlet waters from the wide, ponded area poured down the steep, constricted valley of the small, south-flowing, preglacial stream, to debouch on the outwash plain of Pony Hollow. It was undoubtedly a violent torrent, because of the tremendously augmented volume, in comparison with that of the small brook preglacially there. If the descent was initially as a rapids, it was almost certainly quickly converted to a series of step falls, and then to a single straight descent. The gorges are cut in the Cayuta shale member, 600 feet thick, of the Chemung formation of the Devonian (Williams, Tarr, and Kindle, 1909, pp. 39–40). Sweet (1934) provides, from observation, a generalized section (Fig. 15) of the beds in the region of the gorges. The Cayuta beds are arenaceous shales with interbedded sandstones. Of these sandstones (Fig. 16) one of the thickest is near the top of the section and, according to Sweet (1934), may well have served as a cap rock for waterfall recession. The very weak shales below it, together with the fact that the sandstone is itself laminated and little resistant, would insure rapid recession of the crest of the fall.

The fall was eliminated when the crest had receded to the position of the summit level of the col. Its disappearance was, however, offset by the enhanced flow that, at least temporarily, coursed through the

gap by reason of the draining down of the lake to lower and lower levels. Sweep erosion under such conditions could be extremely efficacious in the weak shales. Thinner sandstone layers lower in the section maintained the fall-factor in the erosive process in some measure and provided rock fragments for scour erosion. Thus the floor of the gorge was reduced throughout its length to an uninterrupted, extraordinarily perfect, uniform, low gradient.

FIG. 16.—Sandstone bed in the Cayuta shale member on the east side of the Upper Gorge, Cayuta Lake drainage.

This interpretation of the manner of erosion of the Cayuta gorges finds confirmation in the preservation of an analogous occurrence in an uncompleted state. Near Slaterville Springs, N. Y., described by Rich (1908, pp. 528–30) and illustrated in Figure 17, a short-lived, glacial drainage developed a gorge and waterfall in rock beds similar to those of the Cayuta site, but there the flow ceased before the bisecting gorge was completed. There remains, in consequence, a relict, dry, or "fossil," waterfall. It will be noted that the retreat of this fall, while the channel was functioning, was

sufficiently rapid to preclude the erosion of a plunge-pool basin at any point, and that the gorge floor has a uniform low gradient. These are precisely the characteristics of the Cayuta Gorges (Figs. 7 and 18). The low gradient is exemplified by the Upper Gorge, still functioning as the outlet to Cayuta Lake, which descends only 20 feet in one and one half miles.

As the ice of the Odessa–Cayuta Lake–Alpine lobe shrank in height and volume, with the decline in intensity of glacierization, the margin of the ice occupied lower and lower positions on the rock hills. As often as, in consequence of this downslope recession of the ice front, a lower col was made

FIG. 17.—View downstream from the crest of the dry waterfall of the channel near Slaterville Springs, N. Y. Weathering wash, from the left, has somewhat modified the flat bottom of the channel.

available, the overflows shifted to the lower escape, and both the levels of the lakes and their expanses were reduced.

The highest level overflow at 1680 feet, previously described, was abandoned for one nearby only a few feet lower. This second route was utilized for only a short time. At the next stage, cutting of the Upper Gorge was begun. The col between the Upper Gorge and Middle Gorge sections was at about 1580 feet. When the barrier of the Lower Gorge had been reduced to the elevation of 1300 feet, the col in the Middle Gorge began

to function, because that appears to have been its height. At this stage, accordingly, there may have been three lakes, the largest source lake at 1580 feet, the second one at 1300 feet, and the third one at such level below 1300 feet as the col in the Lower Gorge had been reduced. During this stage the two lower cols presumably were concurrently reduced, eventually eliminated, and the cutting of the Middle and Lower Gorges thus completed. The secondary lakes then disappeared. Meanwhile the height of the col in the

FIG. 18.—Flat bottom of the Middle Gorge of the Cayuta series.

Upper Gorge had been reduced and the source lake brought down to a level of 1400 to 1500 feet (Fig. 19). This range of levels seems to have endured for a considerable period, for they mark the altitude of the deposit of the hanging deltas previously referred to.

It is interesting to note that the ice barrier held firm throughout this period of gorge cutting and that all three gorges were eroded in conformance with the local base level of Pony Hollow at 1140 feet. In other words, the present level, 1272 feet, of Cayuta Lake was established before the ice-blockade disappeared.

Finally the ice margin did so far shrink back that egress was afforded to the broad Cayuta valley at a point below the site of the morainic blockade. This escape was first by way of the tributary valley from the east which comes in between the Middle and the Lower Gorge, and then by way of a similar tributary between the Middle Gorge and the Upper Gorge. That the Middle Gorge and the Lower Gorge were abandoned for the lateral escapes, by way of these tributaries, indicates that the gradients of the

FIG. 19.—Block diagram of the functioning of the three gorges with the waterfall crest in the Upper Gorge at the altitude of 1480 feet.

tributaries must preglacially or interglacially have been lower than that of the Lower and Middle gorge floors, in order that the drainage could be diverted to them. It is also significant that the shrinking ice barrier persisted long enough, after the erosion of the channel through the outwash at the end of the Lower Gorge, to permit the downwearing of the rock floors of the Middle and Upper Gorges to conformance with the grade of the lateral escapes, via the tributary streams. Allowing for alluvial fill and weathering waste, the floor of the Lower Gorge appears to be at least 40 feet above the

level of that of the Middle Gorge. The permanent barrier of moraine, although only a few feet higher (*vide supra*) than the present lake level, has prevented a similar escape to the Cayuta Valley from the route of the Upper Gorge, which still functions as the outlet channel.

Delta at the outlet of the Lower Gorge. A further phenomenon, indicative of the time relations of the gorge cutting, is the presence of a low, bisected delta exactly at the outlet of the Lower Gorge. The deltaic origin

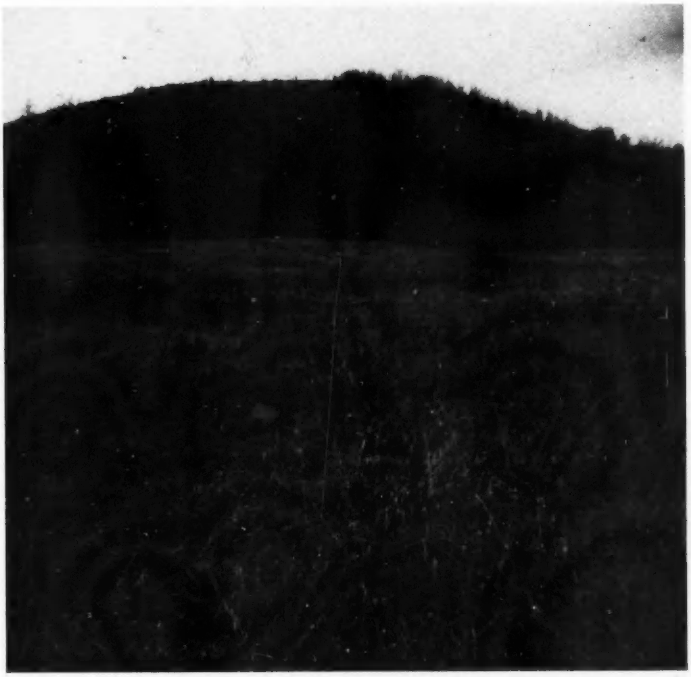

Fig. 20.—Abrupt slope of the northeast margin of the delta at the mouth of the Lower Gorge.

of this deposit was suspected by Sweet (1934) and confirmed and described by Le Roy (1938). It rises visibly only five feet above the level of the outwash, but the outwash may bury its lower portion, as the outwash is the later deposit. The higher deposit is not an alluvial fan, as it has a nearly flat top which changes abruptly to a steep slope at the margin (Fig. 20).

The existence of the delta is indicative of the presence of standing water at the outlet of the Lower Gorge while it was being eroded. This could result

from the blocking of both the Odessa-Alpine valley and the Cayuta Creek valley by the ice, the latter at the place where it flows into the hill region to the south. The water then impounded over the Pony Hollow valley area would be compelled to overflow around the nose of the hill east of the village of Cayuta. This inference is confirmed by the occurrence of an overflow channel at the site (Fig. 21). When this ice "stopper" in the neck of

FIG. 21.—Overflow channel in the nose of the hill east of Cayuta, N. Y., village, 365 feet above the level of the present valley floor on outwash deposits. *Photograph by Le Roy.*

the Cayuta Creek valley was effective, that is, in the final stage of its blocking the Cayuta Creek escape, the overflow water crept past between the hill and the ice margin at an elevation only a little above that of the present drainage. It was presumably at this stage that the Cayuta Lake drainage came into existence, and that the Lower Gorge was excavated and the delta deposited at its outlet into the shallow lake. Before the Lower Gorge

erosion was completed the Cayuta Creek escape was freed of ice. The lake over the Pony Hollow area was drained and the delta bisected by the outlet stream. Still later, when the supply of outwash from the east was cut off, the outlet stream eroded the flat-bottomed channel into the aggraded gravels.

MARGINAL VS. OVERFLOW GLACIAL DRAINAGE

Marginal Drainage in Alaska

A number of years ago the present author (von Engeln, 1911) published a paper on glacier drainage and wastage in which a number of pages (122–132) were devoted to a description of drainage marginal to the Hidden and Variegated Glaciers, Alaska, incident upon a marked advance and expansion in volume of these ice tongues. Here it suffices to restate that a stream, flowing along the lateral margin of the Hidden Glacier, demonstrated to have functioned only for three years or less, had cut a gorge, in friable rock, four to six feet wide and six to nine feet deep. Even more impressive was the performance of a stream marginal to the Variegated Glacier. Under circumstances similar to those of the Hidden Glacier stream, the one marginal to the Variegated Glacier had eroded a gorge in granite three fourths of a mile long, 20 to 40 feet wide, and 50 to 60 feet deep. Although it could not be certainly demonstrated that all the erosion of the Variegated stream had been accomplished within the three year period known to apply in the Hidden Glacier instance, there was evidence of extreme recency of the development. Alongside the gorge, at higher levels, were two parallel channels, apparently occupied for only short periods, cut down to the bedrock in morainic deposit. Further, the surface of the granite, in bands 30 or more feet wide on both sides at the top of the gorge, had been freshly swept clear of moraine. The ensemble of phenomena justified the inference that the Variegated Glacier stream, like that alongside the Hidden Glacier, had been in existence for only a short period.

This type of marginal glacial stream may be appraised as superlatively competent as an erosive agency. Optimum sediment load in amount and texture, flood-flow volume, turbulence, and a high gradient are all present to insure a maximal rate of downcutting. Although instances of such nature probably occurred in association with the margins of the Pleistocene continental glaciers (Rich, 1908), the much more common development of diversion of drainage involved ponding and overflow, as described above for the Cayuta Lake history. Under such circumstances sediment load is lacking, or nearly so, and erosive efficacy depends on volume, steep gradients, and favoring rock structure.

Instances of Overflow Drainage

Niagara. The outstanding instance of overflow drainage, one still in progress of development, is Niagara. Instead of a simple barrier, the factors of diversion, drift filling, and glacial erosion that brought the Great Lakes system into existence are complex, and in some aspects obscure. But the Cayuta Lake drainage history is, in miniature, that of the Great Lakes. There is in the Great Lakes system the same overflow of cols which begins downstream at the Thousand Islands and Lachine Rapids, is repeated at Niagara Falls, at the Detroit and St. Clair Rivers, and at the Soo.

Clark Reservation (Green Lake) N. Y. The counterpart of Niagara, in simpler relations and likewise uncomplete, but in this instance of abandoned development, is seen at the Clark Reservation (Green Lake) south of Syracuse, N. Y. This site was first described by Quereau (1898), and a year later by Fairchild (1899), followed by another paper (Fairchild, 1905). This site is illustrated by Figures 22 and 23. Here the glacier front was established along the crest of the Onondaga escarpment and ponded north-flowing drainage (plus meltwaters from the ice) to a height which brought about overflow along a course from the Onondaga Valley (terminated by the Valley Heads moraine at Tully) to an escape over the brink of the Onondaga escarpment at Jamesville, N. Y. In similar fashion Niagara Falls was initiated by the plunge of the Great Lakes drainage over the Niagara escarpment at Lewiston, N. Y. Just as the ice front, although still blocking the Thousand Islands col, had receded from the Niagara escarpment, so also had the ice front shrunk from the Onondaga escarpment in the Jamesville area. There were the same cap rock and plunge pool (Green Lake) conditions, but on the Onondaga escarpment the overflow was maintained only long enough for the fall crest to recede for a short distance.

Further narrow recession of the ice front from the Onondaga escarpment led to the occupation of what Fairchild (1899, pp. 60–61), who wrote voluminously on the subject of overflow channels in their relation to the levels of the proglacial Great Lakes and the similar lakes in New York state, describes as "the handsomest glacial lake outlet channel in the State." This later became known locally as the Railroad Channel, "because it is the route of the Delaware, Lackawanna, and Western railroad into Syracuse." This channel "is two miles long, 800 to 1000 feet wide at the bottom, and 125 to 150 feet deep. The floor is nearly level throughout the breadth and length of the channel."

The Elmira cutoff. The Elmira cutoff is the classic example of glacial diversion of drainage. Figure 24 reproduces part of the Elmira, N. Y.,

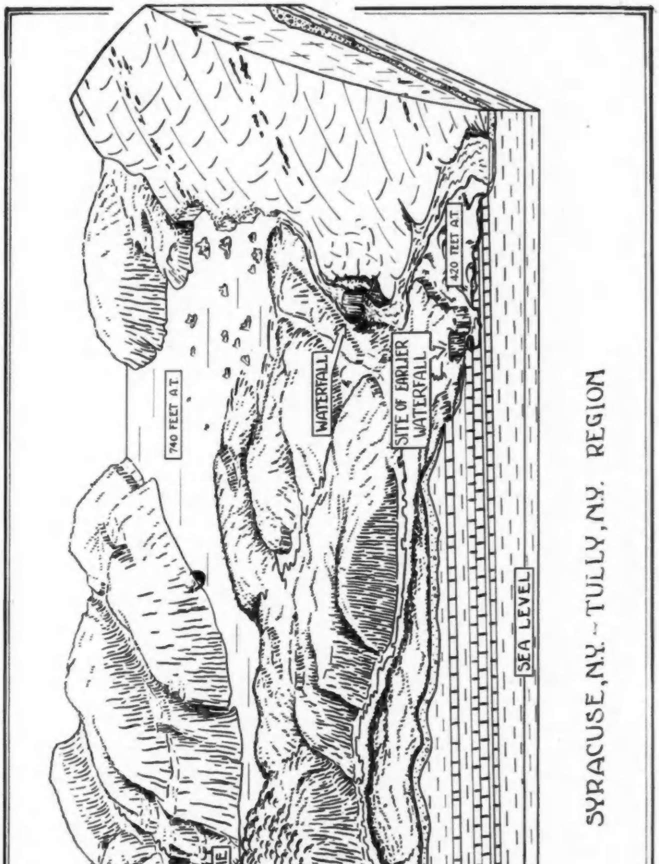

FIG. 22.—Pleistocene ponding and overflow at Clark Reservation (Green Lake) near Syracuse, N. Y. *Drawing by Steve Barker.*

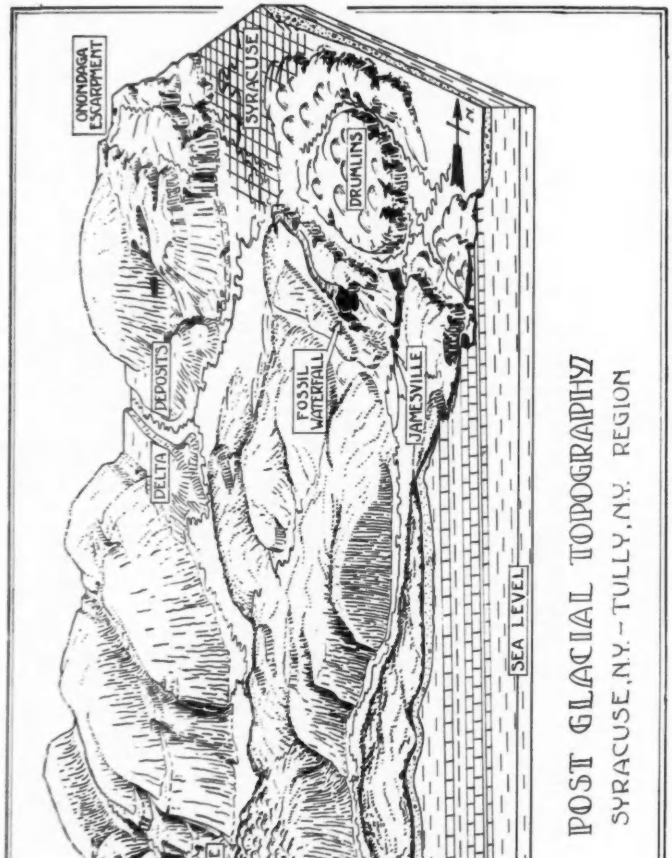

FIG. 23.—Present topography at Clark Reservation (Green Lake) near Syracuse, N. Y. *Drawing by Steve Barker.*

topographic sheet of the U.S.G.S. It will be noted that the Chemung River leaves the mature, open valley, that was obviously once its course, to pass behind massive rock bastion (the northwestern part of which is called Hawes Hill) in a much younger, almost gorge-form valley, before again entering a broad, old valley at Elmira. The cutoff valley flares in both

FIG. 24.—The Chemung cutoff, Elmira, N. Y.–Pa. quadrangle. Lettering and arrows indicate items and relationships referred to in the text.

directions from a central section, where it is of minimal width and where the walls are highest. The south wall of the narrow part of the cutoff is steep, in places nearly vertical, with buttresses and recesses at the summit, developed by differential weathering, and patterned by the jointing of the rock. The stream flows over and between morainic deposits.

To the west and north of the village of Southport a short, flat-floored, dry channel leads from the valley of Seely Creek to the lower course of the present Chemung River near Elmira.

The abandoned parts of the older valleys, that is, the tracts, around Horseheads and Big Flats, were the place where the preglacial Chemung River either joined, or was joined by, a stream coming from the north that had its course along the axis of the Seneca Lake Valley. The rock floor of this area of older valleys is deeply buried under morainic, lake clay, and outwash gravel deposits which have a nearly level surface at a maximal altitude of 903 feet at Horseheads, which is an elevation of 23 feet above the level of the upstream entrance to the cutoff course.

Such are the attention-compelling features of the site. The first field study directed to an elucidation of the phenomenon was made by N. H. Farnham (1898). Farnham's findings are referred to and accepted by Tarr (1898, pp. 388–89, 168–170). Both Farnham and Tarr conceive that, preglacially, two opposed small tributaries to the old Chemung course (similar to the present Hoffman Brook and the unnamed drainage flowing northwest from the col in the summit of Hawes Hill) had, by competitive headwater erosion, greatly lowered the divide between them. Then the whole area was occupied by the Pleistocene glacier. At the close of the glacierization, the northward shrinking and thinning front freed this col of ice while the valley between Horseheads and Elmira was still occupied by a glacier tongue. Accordingly, the waters of the upper Chemung followed the cutoff route, and were postglacially compelled to continue in this course because the fill of outwash was built up to a higher level in the Horseheads area than at the upper entrance to the cutoff.

The chief fault of this interpretation is the improbability of development of a sufficiently low col across the hill by the headwater erosion of the competing small streams. Comparable streams in the same locality have not achieved such results. Tarr sensed this difficulty, hence added the suggestion that "the glacial floods choked these small tributaries (i.e., those of the cutoff) with sediment until their bottoms were raised above the level of the divide between them." Although Farnham and Tarr knew that the rock valley of the cutoff was much deeper than the present floor on glacial debris, both authors, if they realized that this circumstance made their interpretations inadequate, avoided the issue.

Tarr (1905, pp. 234, 237, 239, 240), reverting to the topic seven years later, was still of the conviction that "the course of the Chemung west of Elmira is determined by outwash." After weighing other possibilities, he is also confirmed in his opinion that headwater erosion accounts for the col lowering. In this connection he makes much of the small flat-floored valley

north of Southport. This he regards as a relic col from preglacial times, analogous to that which preglacially existed in the line of the cutoff. He finds it exceedingly difficult to conceive any set of conditions by which ice-born streams, either overflow or marginal, could cut the complex of channels at Elmira, or by which they could develop the doubly flaring condition of these valleys. Reference is made to Niagara to indicate the incompetence of lake overflow streams to erode rock gorges. (Curiously, the fact of the Niagara gorge below the falls is not referred to.)

In 1908 Salisbury and Atwood (pp. 62–63 and Plate CXV) gave the Elmira cutoff wide publicity. They assert it to be a "drainage modification caused by the drift." They cite Tarr, but simplify his interpretation to the effect that the deposits compelled the stream to follow the "course of a tributary valley" without further elucidation.

In 1909 Tarr (Williams, Tarr, and Kindle, pp. 221, 224–225) recognized that "glacial waters ponded in the upper Chemung by an ice dam might well have formed just such a gorge" (p. 221). In the later pages he wholeheartedly accepts the idea that glacial-lake overflows were responsible for cutting down this and other divides, and assigns the advance of the first of two ice invasions as the time when the gorge cutting was accomplished. The Southport valley receives only a descriptive mention (p. 19) as an example of small tributaries with low valley-floor divides and "valley sides rising high above them."

There the discussion has rested until now. In the light of the present study the sequence of events at Elmira appears to have been as follows. In the first glacierization an ice tongue, pushing southward through the Seneca Lake Valley in advance of the main ice front, expanded as a piedmont bulb in the tract around Horseheads, with lobes extending westward and southward, when it escaped the confining walls of the feeding valley at the north. As this piedmont bulb grew in area and swelled in thickness it blocked the course of the Chemung, and a lake was impounded in the upper course of the river by the western margin of the ice. For a time the Chemung waters probably escaped through channels between the ice and the northern slope of Hawes Hill. But when the ice had reached a certain elevation on the hill, the level of the lake was raised to a height that permitted overflow across the lowest col among the drainage divides between small streams flowing toward the east and toward the north. The counterpart of such a col still exists on Hawes Hill (Fig. 24).

Thus far the analysis is substantially in accord with the findings of the other observers. However, these earlier students, despite the occurrence of dry, relic, waterfall sites and gorges, and the living example of Niagara, failed to grasp the significance and potence of waterfall retreat in the elimina-

tion of divides between streams heading against each other in sedimentary rocks horizontally disposed. The descent of a large volume of water from a proglacial lake overflow down the steep and narrow headwaters course of a small tributary would be conducive to violent erosive activity, and, with alternations in resistance of the sedimentary beds, would shortly develop caprock waterfall conditions. The rock fragments eroded at the fall would contribute the sedimentary load lacking in the lake overflow and enhance the cutting power of the current in the downstream sections. The *per saltum* lowering of the divide would, at intervals, provide surges of large volume from the impounded lake waters to accelerate erosion and enlarge the channel. The time required to bring about a complete transection would be short. That the ice fronts were stabilized for sufficiently long periods to permit such a development is evident from the history of the Cayuta gorges.

The Southport channel, in the light of this interpretation, is simply a secondary diversion of the same type; one which was developed when the Seneca lobe of the ice had moved forward to the site of Elmira and blocked egress, there, from the cutoff to the main valley. Only a low divide and a short reach needed to be eroded at Southport. The sediment laden current from the cutoff, supplemented by drainage from the margin of the ice, was able to produce this channel in short order (Fig. 24).

The Elmira cutoff was completed at the time of the first glacial advance. As its course was transverse to the direction of ice motion the narrow, water-cut channel was little, if at all, modified by ice erosion. Neither was it filled by glacial deposits, nor sufficiently blocked by them to prevent its use recurrently after each ice retreat and preceding each ice advance. During interglacial and postglacial time the south rock wall was battlemented at the summit by differential weathering along joint planes. The sides and tops of similar valleys in line with the direction of ice motion, on the other hand, have been uniformly smoothed by ice erosion.

The morainic deposits now on the slopes and floor of the cutoff were made during the dissipation of the last glacier. Once the upper course of the Chemung was cleared of ice, drainage through the cutoff channel was immediately resumed. Further retreat of the ice front permitted the deposit of outwash materials over the area of Big Flats and Horseheads and confirmed the Chemung in the cutoff course, because these deposits were built up to an elevation superior to that of the entrance to the cutoff channel.

THROUGH VALLEYS IN CENTRAL NEW YORK

Overflows of Major Divides

Preglacial water partings. The Elmira diversion merely brought about the bypassing of a portion of the preglacial course of the Chemung River.

Much more radical reordering of preglacial drainage was achieved where the reduction of cols by proglacial lake overflows occurred along the east-west line of the major divide between drainage north to the St. Lawrence River and south to the Susquehanna River. The system and succession of proglacial lakes engendered by the ponding of the north-flowing waters, while the last ice melted away, have been much studied and described. These lakes, however, were governed, as to levels and overflow routes, by the existing relief, which has its present expression from great modifications of the preglacial topography; modifications that resulted directly and indirectly from the ice occupations. When the ice first advanced across this line of water parting, the northflowing waters were similarly impounded, but outlets then were determined by the topography of the preglacial divide between the two major drainage systems. The profound modifications of topography and drainage courses that resulted from these first overflows become explicable when interpreted in the light of the evidence made available by study of the Cayuta Lake gorges, of the Elmira cutoff, and of the phenomena associated with these occurrences.

Cayuta Creek drainage. The course of Cayuta Lake drainage downstream from the site of the gorges affords a noteworthy example of such modifications. This occurrence was described by Tarr (1898), with a diagram of the present and preglacial drainage, but, except for references to displacements of the drainage from drift filling, Tarr is completely noncommittal in regard to the cause of the reordering of the stream lines. In a later paper (1905, pp. 234–235, 238–239) he recognizes the marked lowering of the rock divide, but is still at a loss to account for it, except that he rules out "ice-born" streams because of an erroneous interpretation he made of the significance of buried tributaries (p. 239).

It seems clear that, preglacially, the drainage (Fig. 25) from the Cayuta Lake area, and that of the western end of Pony Hollow, went through the Alpine-Odessa valley to join a larger stream in the, now, Seneca Lake valley. A small tributary to this system came from the south and headed up in the highland which was then the divide between drainage westward to the Seneca Lake valley and southward to the Susquehanna River. The valley of this tributary flares, appropriately, toward the larger Pony Hollow valley. As was true during the melting away of the last ice, a lobe from the first advance of the ice in the Seneca Lake Valley poured into the Odessa-Alpine opening and blocked the drainage that had followed this course. The ponded waters extended far eastward in the Pony Hollow valley, which had a rock divide between it and eastward drainage, near the present village of Newfield. This divide appears to have been high, or else eastward overflow was blocked by ice in the Cayuga valley. Accordingly,

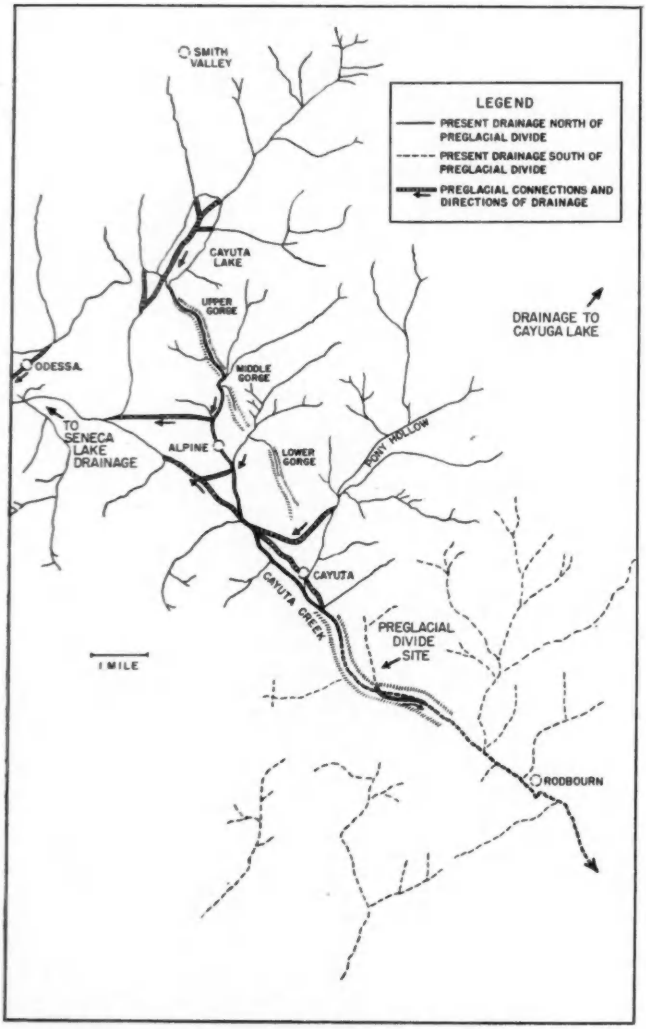

FIG. 25.—Preglacial and postglacial linkage of drainage in the Cayuta Lake and Cayuta Creek region.

the escape was over the lower col at the head of the tributary from the south, as is shown in Figure 25.

There followed the familiar history of gorge cutting by waterfall retreat. Where the divide was transected, the present Cayuta Creek flows southeast through a narrow defile (between Cayuta and Rodbourn) beyond which the valley flares again.

Unlike the Elmira cutoff, the gap made by the Cayuta overflow was aligned with, not athwart, the direction of the ice advance. Accordingly, the forward moving glacier eventually crowded into it, and through it, as an active current. Progress in the study of glacier flow, as reviewed in the recent paper by Holmes (1944), has made it increasingly evident that basal currents in continental ice sheets invade and ream out even very narrow original channels in rock, where these can at all serve to facilitate the forward motion of the ice. This was a point that troubled Tarr. In his expositions he regretfully, but regularly, discards such erosion as a possible factor in creating the existing gaps across former rock divides.

Although he, later, himself found the evidence to demonstrate the fact, Tarr struggled also, in his early interpretations of these diversions of drainage, from lack of conviction that there had been in central New York even two ice advances, separated by a long interglacial interval. He speculated cautiously in regard to the possibility of marked changes during the *advance* of one glacierization, but could not bring himself to attempt a visualization of the effects of multiple glacierization.

As a consequence he misinterpreted completely the significance of drift-buried gorges tributary to the water- and ice-eroded defile section of the Cayuta Creek drainage (Fig. 26). After the first ice had melted off, small streams, tributary to the preglacial southward drainage, terminated, as hanging valleys, high above the floor of the deep defile through the erstwhile divide area. During the interglacial age that followed, these tributary streams, now provided with steep gradients, rapidly excavated their valleys to accordance with the main valley. A second advance and melting off of the glacier provided the debris for filling the trenches cut in interglacial time. It also furnished the morainic material which mantles the slopes, and the outwash which now forms the floor of the main valley.

Instead of being inexplicable, such dissected areas, with drift-filled tributary valleys, are actually so much of a departure from the general pattern of the topography in the region of the preglacial water partings, as to constitute conspicuous earmarks of sites where there has been a transection of former rock divides by joint water erosion and glacial erosion. On a combined map, made up of a number of quadrangle sheets of this general area, these sites, like that of the Cayuta Creek instance (Fig. 26), stand out challengingly from the rest of the topography.

FIG. 26.—Cayuta Creek, Waverly, N. Y.-Pa. quadrangle. Young valleys, interglacially eroded, tributary to Cayuta Creek between Reniff and Junction, have drift-mantled sides and floors. The area around Owens Mills is representative of the upland topography where this is unaffected by the transection of preglacial divides. A high-level, temporary, overflow site is shown in the headwaters area between Dean Brook and Dean Creek.

Through Valleys

Cayuta Creek is only one of a large number of such transections of the preglacial, major rock divide between the St. Lawrence and Susquehanna drainage basins. Another, almost exactly comparable instance, is that of the Tioughnioga River valley south of Cortland, N. Y. This site was early described by Carney (1903), and commented upon also by Tarr, who, as in the case of Cayuta Creek, has misgivings in ascribing the divide transection either to stream action or to glacial erosion. It is too narrow and gorge-like for the latter, he says. Another example of this type is that of the course of the East Branch of Owego Creek, which follows a doubly flaring valley through a narrow defile at Richford, N. Y.

These, and others, are all examples of the phenomenon of the *through valley,* a term coined by Professor W. M. Davis in discussing such occurrences, as described by Professor Tarr at the Philadelphia meeting of the Geological Society of America in 1904. Davis applied it to the "condition of valleys connected across lowered divides." The through valley has, however, much more impressive development, than those referred to above, at places where the contribution of ice erosion to such excavation was of great magnitude. The Cayuta, Tioughnioga, and Richford occurrences are in fact the, in a sense, unfinished jobs that afford clues to understanding of these greater exhibits, much in the same way that the Cayuta gorges and the Elmira cutoff give the lead to an appreciation of how the divides were originally bisected.

The more imposing examples of these through valleys are indicative of tremendous widening (probably deepening also) by glacial erosion after overflow gorges had first been trenched across the divides. An outstanding example is that of Six Mile Creek, south of Ithaca, N. Y. (Fig. 27).

The development of these great trenches has in the past been attributed solely to glacial erosion. Broad low grooves have been cut across the uplands at places where erosion from overflow waters could have made only a minor contribution to their development, which is obviously the product of glacial erosion. A representative example of such a groove occurs 3 miles northeast of Cortland, between the West and East Branches of the Tioughnioga River, on the Cortland, N. Y., topographic sheet. Another is that of Buttermilk Creek and Danby Creek on the Dryden topographic sheet. Hence the possibility exists that the great through-valley troughs, such as that pictured in Figure 27, are also due exclusively to ice erosion. However, these large through valleys occur at the sites where a major ponding of waters in proglacial lakes by the advancing ice may be inferred, and where the basal currents of the ice, advancing across the territory, would be

of especial intensity and erosive potency. Thus the large north-south valleys of the Finger Lakes of New York are commonly continued southward by through valleys of impressive dimensions. This is the case with Seneca, Cayuga, Owasco, Skaneateles, and others of the lakes. It is true that the through valleys may be choked with moraine, and that morainic barriers may rise high above their rock floors, as in the case of the Onondaga trough at Tully, N. Y., south of Syracuse, but the steep, ice-truncated, rock walls give clear indication of their uninterrupted extension past such accumulations.

FIG. 27.—Through valley of Six Mile Creek near Brooktondale, N. Y. *Photograph by A. W. Abrams.*

These vast troughs, as is true also of those like Cayuta Creek of more modest expression, are the product of ice advances antedating the last, which was, presumably, the Wisconsin ice invasion. This last ice found the way prepared for it, the country had been modeled by the earlier ice advances to accommodate a glacial flood. Moreover, the last ice apparently was of less volume than that of advances which preceded it. Accordingly, it was incapable of enhancing, or even modifying greatly, the forms from erosion created by the earlier glacierizations.

INTERGLACIAL CONSEQUENTS

The evidence for this conclusion is to be found in the traces of interglacial developments left unerased by the last ice. Large gorges were excavated, interglacially, in the hanging-valley floors of the larger preglacial tributaries to the principal drainage in the lines of the through valleys. Such erosion resulted from the new base levels established by the cutting of the through valleys. These interglacial gorges were, in large part, effaced by the morainic fill deposited by the last ice, and new gorges, the counterparts of those eroded interglacially, have postglacially been cut into the slopes.

Even more convincing, in support of the interpretation that the through valleys are a production of the first ice advance, is the phenomenon of consequent streams, as observed by the present author, and set forth in a study by Wold (1942). Numerous small streams course down the steep sides of the through valley troughs. These streams are obviously postglacial consequents. Minor drainage has cut through the thin cover of drift that mantles these slopes (a "new" land surface) and has slightly notched the underlying bedrock. If these rock slopes existed before the last ice advance, then similar consequent drainage should have developed upon them in interglacial time. Such channels, drift-cloaked, parallel to the postglacial courses, do occur and are commonly now devoid of significant drainage. A slightly different disposition of the shallow drift cover has shifted such minor consequent drainage to new lines. Their presence is validating evidence of the first importance, because it proves that the last ice advance was incompetent to erase the shallow interglacial consequent valleys from the steep sides of the through valleys. The "new" slopes, on which such consequent drainage has developed, were present in interglacial time and were little if at all modified by the glacial erosion of the last ice advance.

ARCUATE DRAINAGE PATTERN FROM OVERFLOW DIVERSIONS

Arcuate Pattern of Glacially Diverted Drainage

A characteristic result of glacial diversion is the arcuate pattern of the reorganized drainage. This result has been much written about in reference to specific instances, but the duplication of the arcuate courses, as a recurrent identifying pattern, has apparently not been appreciated.

It was early recognized that the continental glacier regularly terminated in broad lobes. This is so pronounced a feature of the fronts that the appropriate designation for a particular section of the ice is to refer to it as this or that lobe. In turn, the curved peripheries of the lobate fronts governed the routes of drainage marginal to the ice, and, in many places, established it in courses from which it did not postglacially escape. This

bowing of major drainage lines was, as in the case of the various types of diversion described above, brought about chiefly by the cutting of overflow channels. The ice front was a barrier which drainage directed against it could not surmount. Ponding and lateral overflows were, therefore, compelled. This has long been known and described in detail for the outstanding examples of such diversion and reorganization of major drainage courses, those of the present Ohio and Missouri Rivers. What has not been appreciated is what it has been the endeavor to demonstrate in the preceding pages, namely, that such overflows could excavate adequate, deep channels in remarkably short periods of time, geologically speaking. If a lobate front of the ice was maintained in one position for any appreciable period, gorge cutoffs across intervening divides could be, and were, excavated. The larger the volume of drainage impounded, the more effectively and completely the arcuate course, marginal to the ice border, was established. Melting back of the front from such a position did not result in any departure from the course fixed by the diversion.

Minor Occurrences of the Arcuate Pattern

It is not the purpose here to review the literature in reference to the Ohio and Missouri diversions, as the author knows these only from casual observations at noncritical points in their courses. Instead, it is intended to point out that the phenomenon is also present, less conspicuously, in the New York state region, with which this paper is chiefly concerned, and to suggest that, by analogy, it may be recognized in other instances where it is only obscurely in evidence.

Thus the curved course, toward the southeast, pursued by the Cayuta Creek overflow, is matched by a similar curved course, to the southwest, followed by the Catatonk Creek. Next south, the Cohocton River makes a similar arc, and transects a preglacial divide at Cohocton, N. Y. Still farther south, the Canisteo River, in a parallel arcuate course, cuts across a preglacial divide at Cameron, N. Y. Another example is afforded by Oil Creek and Campen Creek in Allegany County, N. Y.

A third and very conspicuous example on the topographic maps is that of Cattaraugus Creek, which is the boundary line between Cattaraugus County, N. Y., and Erie County, N. Y. The extraordinary east-west course of this stream appears inexplicable, except by reference to its establishment along an ice border in the manner described. No systematic study of Cattaraugus Creek is on record in the bibliography and index of North American geology.

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